NIPER-77
Distribution Category UC-92
July 16, 1985

TOPICAL REPORT

HISTORY MATCH OF BODCAU IN SITU COMBUSTION PROJECT

By

Mark A. Young

Work Performed for the
U.S. Department of Energy
Under Cooperative Agreement
DE-FC22-83FE60149

NATIONAL INSTITUTE FOR PETROLEUM AND ENERGY RESEARCH
A Division of IIT Research Institute
P. O. Box 2128
Bartlesville, Oklahoma 74005
(918) 336-2400

CONTENTS

ILLUSTRATIONS

HISTORY MATCH OF BODCAU IN SITU COMBUSTION PROJECT

by Mark A. Young

ABSTRACT

The Bodcau In Situ Combustion Project has been successfully history-matched using a state of the art finite-difference thermal simulator. The final simulation yielded a good match to monthly oil production rates. The simulation predicted a cumulative oil production of 746,650 bbl which is in good agreement with the total production estimate of 700,000 bbl. The simulation results were sensitive to gas mobility, combustion reaction rate, and heat liberated by the combustion reaction. The experience gained in this work will be useful in predicting the performance of other in situ combustion projects.

INTRODUCTION

The history-match of the Bodcau In Situ Combustion Project was work performed by the National Institute for Petroleum and Energy Research under a contract with the Department of Energy. This work complements the work done previously (1) in the evaluation of the Bodcau In Situ Combustion Project. In the original evaluation no detailed simulation work was done and no attempt was made to history-match project performance. The objective of this work was to history-match project performance and to identify the important process parameters. The experience gained from this work will be helpful in predicting the performance of future in situ combustion projects. The data used in the history-match were derived from the series of annual reports on the project (2-5). These reports provided detailed geological and engineering data useful in the simulation. The computer program used in the history-match was the thermal simulator ISCOM developed by CMG (Computer Modeling Group). CMG is located in Calgary, Alberta, Canada and the simulations were run on the University of Calgary computer accessed at NIPER via TYMNET.

HISTORY MATCH OF BODCAU IN SITU COMBUSTION PROJECT

The Bodcau In Situ Combustion Project is located in the Bellevue Field, 18 miles northeast of Shreveport, Louisiana on the eastern edge of Bossier Parish (Figure 1). The project encompasses 19 acres and produces from the Upper Cretaceous Nacatoch Sand.

The project consists of five nine-spots. In the project area, the reservoir is an average of 350 ft deep and dips at an angle of 4.5° to the northeast (Figure 2). The reservoir thickness is fairly uniform over the project area and averages 56 ft (Figure 3).

Air injection began in July 1976 and reached 3.5 MMSCFD by February 1977 (Figure 4). The wells were ignited with electrical heaters over a period of 1.5 months. Simultaneous water injection began in April 1977. Air injection was shut down in September 1980, and water injection was increased. The oil production rate for the project increased almost immediately after the start of air injection and ignition. Production reached a maximum of 601 BOPD in March 1978. A production forecast based on Cities Service's previous pilot experience in the Bellevue Field was made. However, no detailed simulation work was published in this prediction. The cumulative oil production from the project was expected to be near 700,000 bbl.

Bellevue crude has an oil gravity of 19° API. The oil viscosity is 675 cp at 75° F and drops to 30 cp near 185° F (Figure 5).

The reservoir properties assumed in the simulation were as follows: porosity, 0.339; permeability, 700 md; reservoir pressure, 40 psig; reservoir temperature, 75° F; initial water saturation, 0.274; initial oil saturation, 0.696; initial gas saturation, 0.03; reservoir thickness, 56 ft.

The simulator used in the history match was ISCOM developed by CMG (Computer Modeling Group). The simulator has a fully implicit formulation. With this simulator, one can specify a variable number of oils and gases. Overburden heat loss and heat storage are rigorously modeled. The simulator has a flexible grid system. Cartesian and cylindrical coordinate options with variable grid sizes may be used. A program may be run in one, two, or three dimensions. The simulator has a flexible chemical reaction model. The user defines reaction rates, reactants, and products.

The components assumed in the present work were water, oil, oxygen, gas (CO_2, CO, N_2), and a solid (coke). The grid used in the simulation was based on ¼ of a nine-spot (Figure 6). A 4x3 areal grid was chosen to make the simulations cost effective. The grid consisted of 1 injector, 3 producers, and 12 blocks. The grid dimensions were adjusted so that the area of the nine-spot in the simulation was exactly one fifth of the project area. The production rates obtained in the simulation were multiplied by four for the nine-spot and then by five for five nine-spots in the project to arrive at total project production rates used in the match.

No laboratory measured relative permeability curves were available so the relative permeabilities were extracted from the simulation (Figure 7 and 8). Only slight modification of the gas/liquid relative permeability curves was required. This modification involved increasing the gas mobility at low gas saturations. The modification improved the simulated production profile by eliminating a spike in the profile.

The dominant chemical reaction in the process is the combustion reaction. In this reaction, oxygen reacts with coke to produce water and gas (CO_2, CO). Upon completion of the history match, the reaction rate was found to be 1.0 mole/ft^3/day, and the heat generated by the reaction was found to be 1.4×10^5 Btu/lb mole. The heat of reaction and stoichiometry of the combustion reaction are in good agreement with values obtained by Lin, et al. (6) and are published in a recent paper. In that work a value of 2.35×10^5 Btu/lb mole was found for the heat of reaction in combustion tube experiments using a 13° API crude oil. The fuel lay-down statistic for the coke was estimated at 0.45 lb mole/ft^3. These parameters are characteristic of the in situ combustion process and are not simply artifacts of the simulation.

The final simulation yielded monthly oil production rates which were in good agreement with those obtained in the field (Figure 9). The simulation predicted cumulative oil production of 746,650 bbl which is in good agreement with the total production estimate of 700,000 bbl. The simulation also yielded monthly water production rates which were in reasonable agreement with those obtained in the field (Figure 10). The agreement improves after the first year of production. The relatively high water production in the first part of the project is attributed to early wet combustion not accounted for in published reports. The air-oil ratio averaged about 17 MCF/BBL for the project. The air-oil ratio obtained in the simulation was in close agreement with this value since a good match to oil production rates was realized and the air injection rates used in the simulation were close to the actual field air injection rates.

We conclude that the Bodcau _In Situ_ Combustion Project has been successfully history matched. The simulation results were sensitive to gas mobility, combustion reaction rate, and heat liberated by the combustion reaction. The experience gained in this work will be useful in predicting the performance of other _in situ_ combustion projects.

REFERENCES

1. Keplinger and Associates, Inc. Evaluation of the Bodcau (Bellevue) _In Situ_ Combustion Project. U.S. Dept. of Energy Report DOE/BC/10033-4, October 1982.

2. Cities Service Company. Bodcau _In Situ_ Combustion Project. First Annual Report, U.S. Dept. of Energy Report SAN-1189-2, September 1977.

3. Cities Service Company. Bocau _In Situ_ Combustion Project. Second Annual Report, U.S. Dept. of Energy Report SAN/1189-2, February 1979.

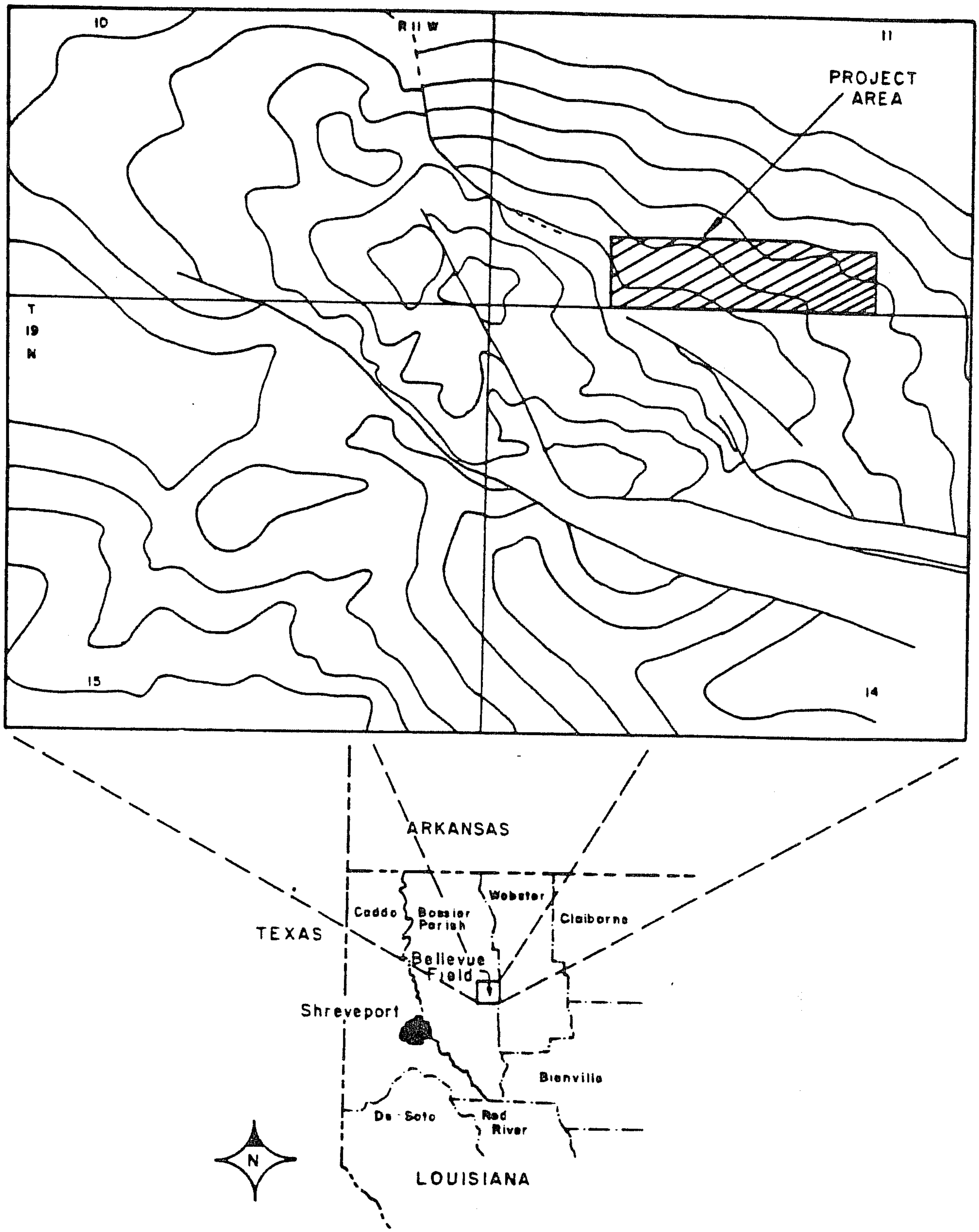
4. Cities Service Company. Bodcau _In Situ_ Combustion Project. Third Annual Report, U.S. Dept. of Energy, DOE/ET/12057-6, August 1980.

5. Cities Service Company. Bodcau _In Situ_ Combustion Project. Fourth Annual Report, U.S. Dept of Energy Report, DOE/ET/12057-8, July 1981.

6. Lin, C. Y., W. H. Chen, S. T. Lee, and W. E. Culham. Numerical Simulation of Combustion Tube Experiments and the Associated Kinetics of In-Situ Combustion Processes. Soc. Pet. Eng. J., December 1984, pp. 657-666.

ACKNOWLEDGMENT

Funds for this project were provided by the U.S. Department of Energy under Cooperative Agreement DE-FC22-83FE60149.

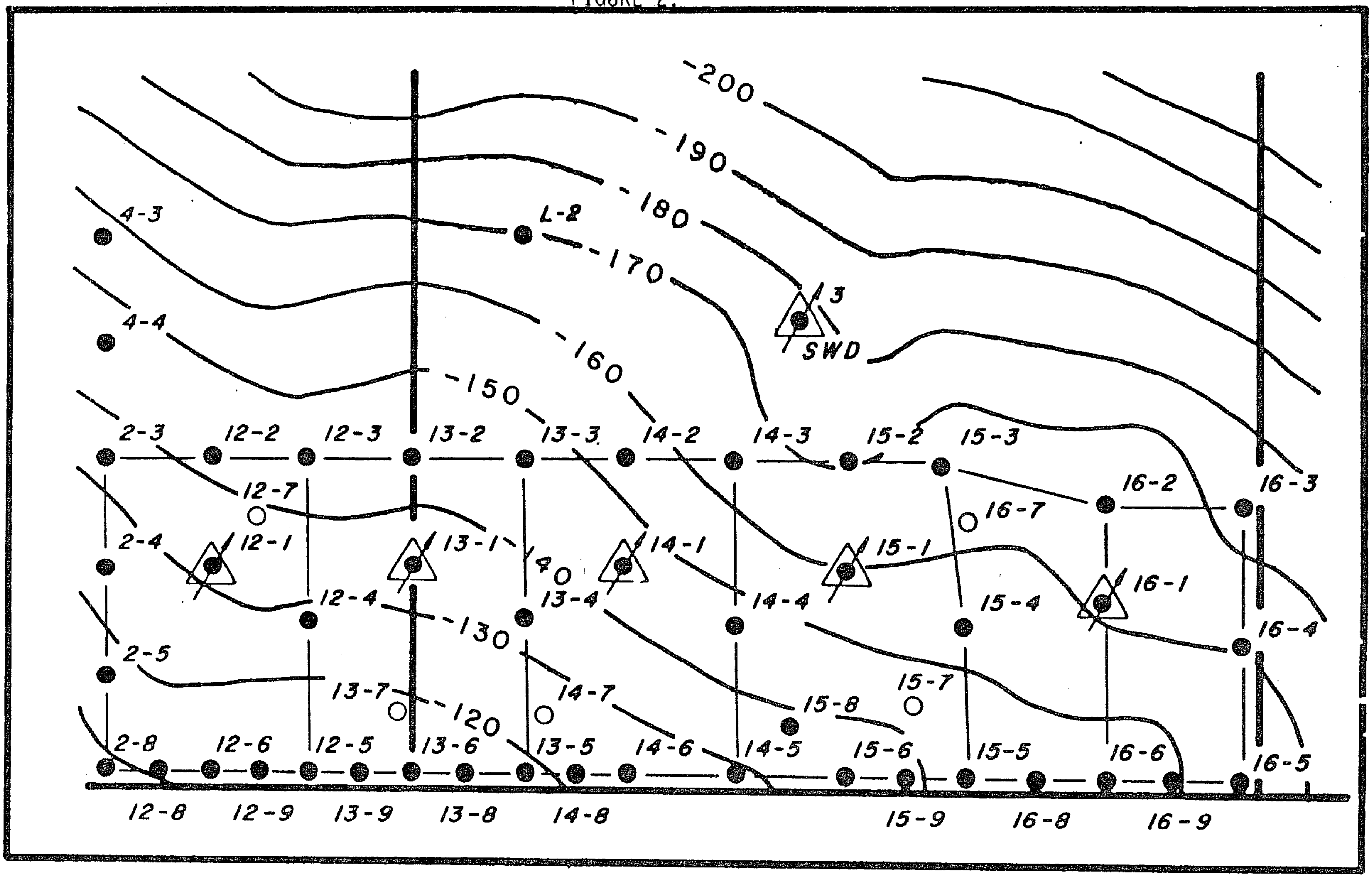


General Location Map

BELLEVUE FIELD

Bossier Parish, Louisiana

FIGURE 2.



PROJECT AREA STRUCTURE MAP

CONTOURED ON TOP OF NACATOCH, SEA LEVEL DATUM

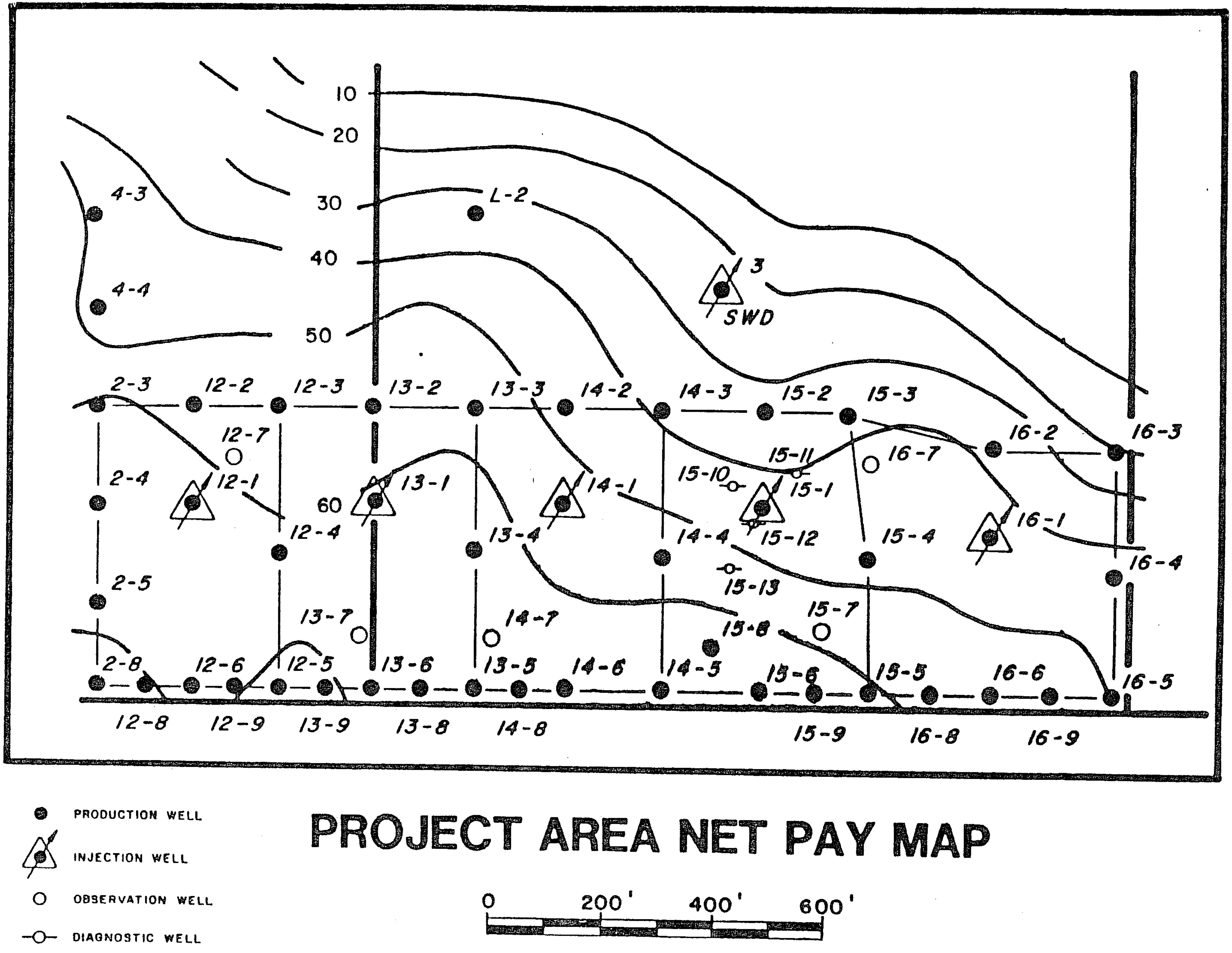
PRODUCTION WELL

INJECTION WELL

OBSERVATION WELL

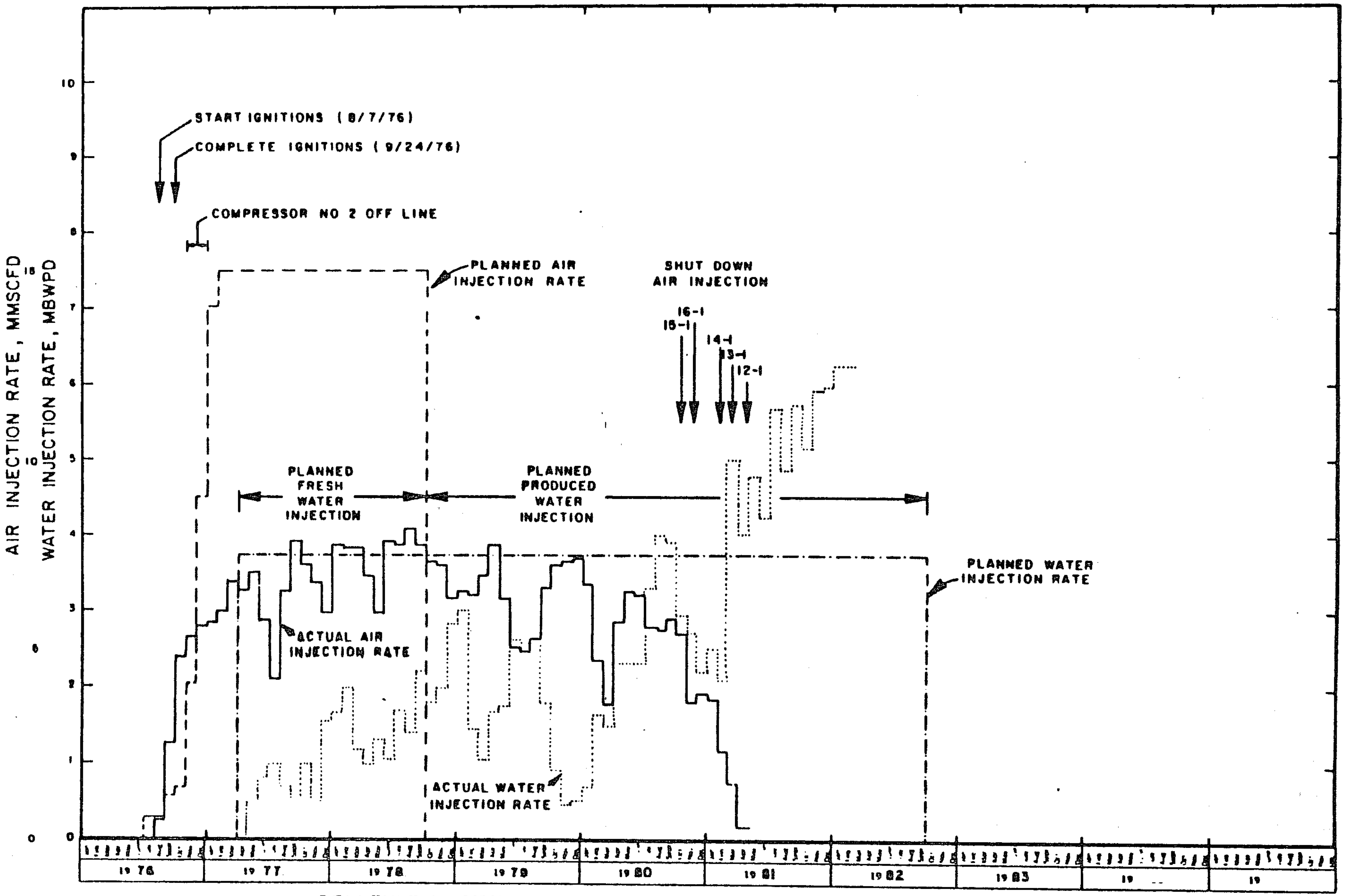
0 200' 400' 600'

FIGURE 3.



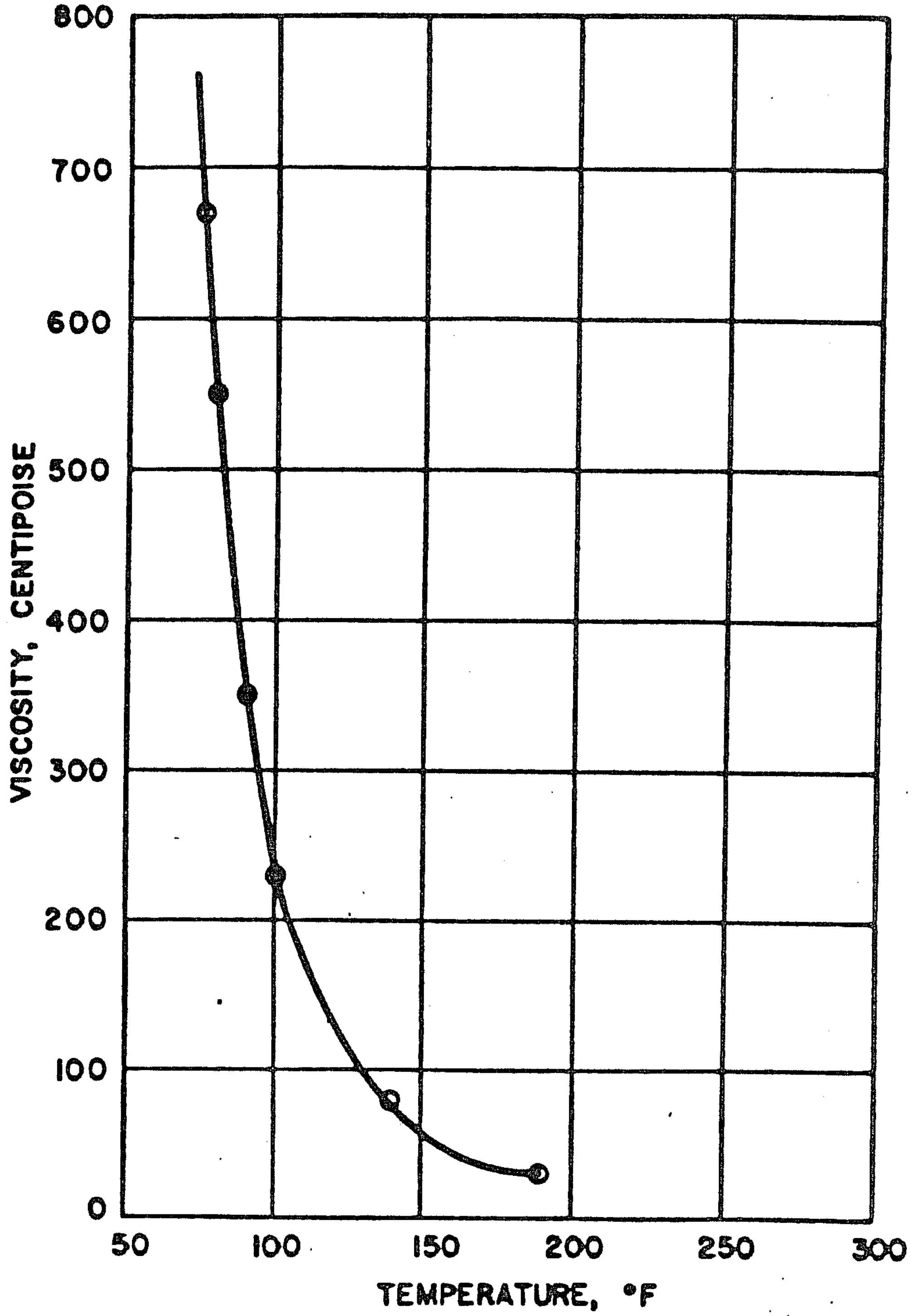
PROJECT AREA NET PAY MAP

FIGURE 4.



BELLEVUE IN SITU COMBUSTION INJECTION PERFORMANCE

FIGURE 5.



VISCOSITY-TEMPERATURE RELATIONSHIP
(19° API, BELLEVUE CRUDE)

FIGURE 6. Simulation grid

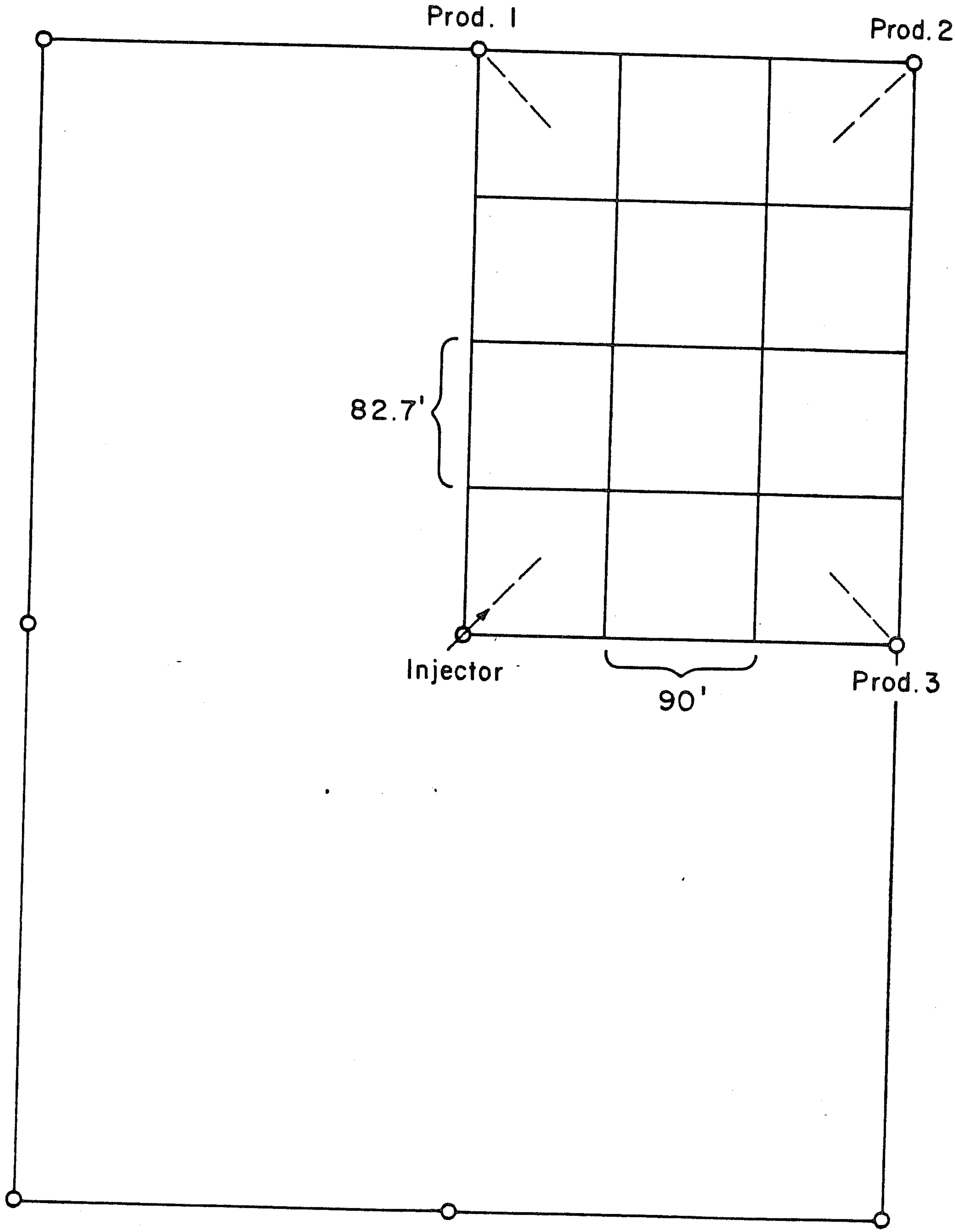


FIGURE 7.

OIL / WATER RELATIVE PERMEABILITY CURVES

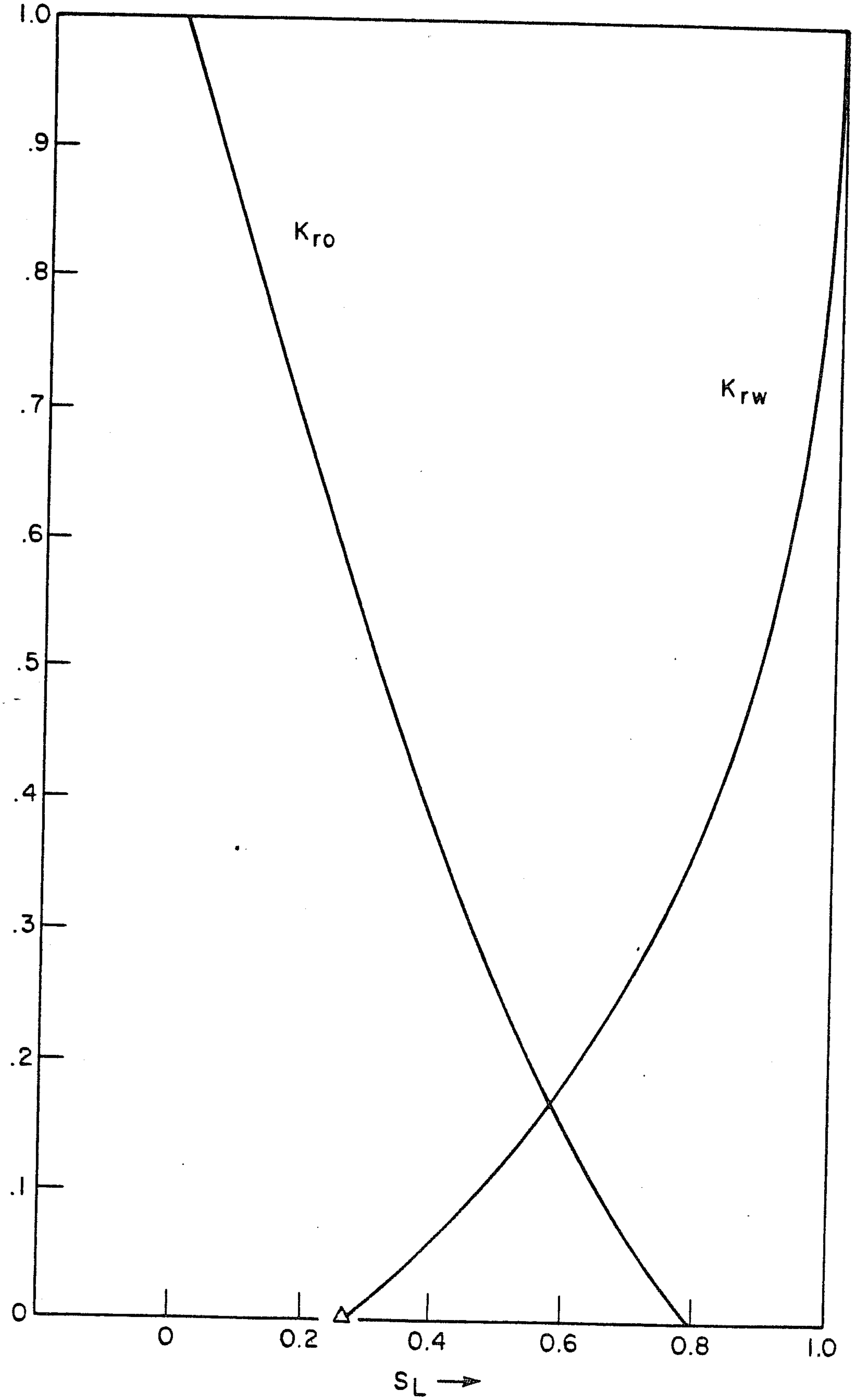


FIGURE 8.

GAS / LIQUID RELATIVE PERMEABILITY CURVES

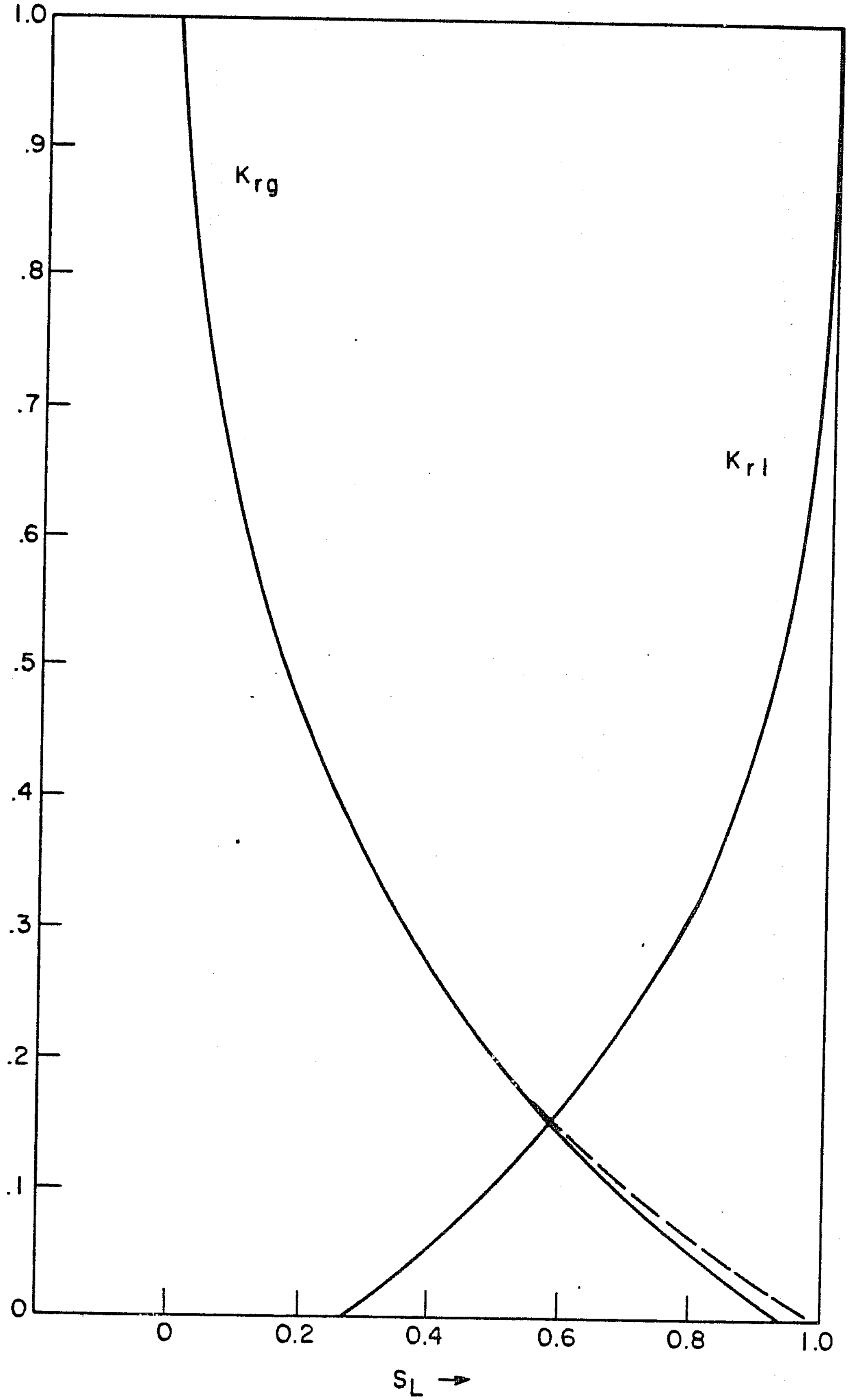


FIGURE 9.

BELLEVUE PROJECT, ACTUAL VS. PREDICTED OIL PRODUCTION

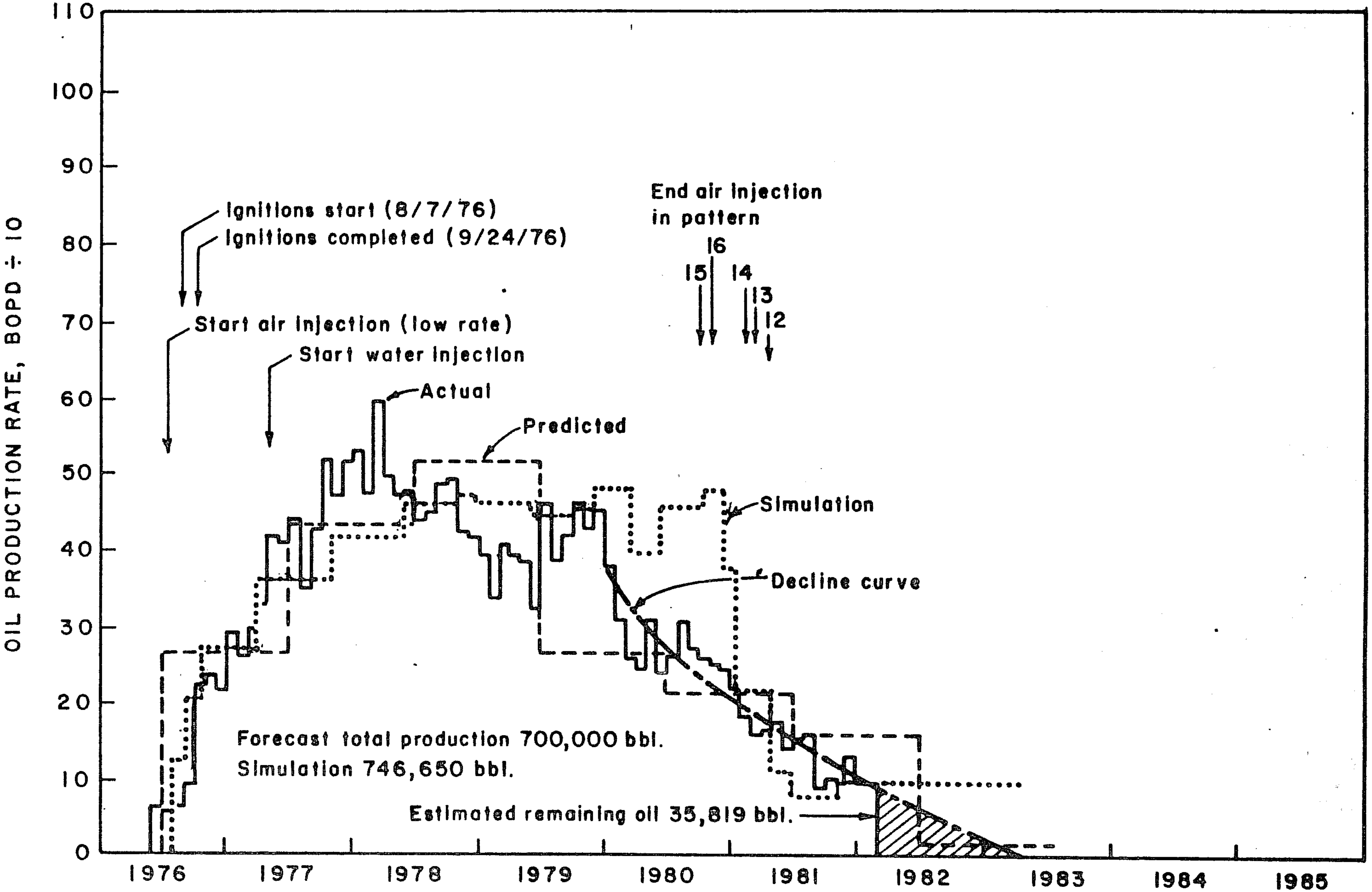


FIGURE 10.

BODCAU IN SITU PRODUCTION HISTORY